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Respiratory Symptoms and Lung Function in Workers in Heavy and Highway Construction: A Cross-Sectional Study

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Background *Occupational exposures for workers in heavy and highway (HH) construction include cement-containing dusts and diesel exhaust (DE). To investigate possible health effects, respiratory symptoms and lung function were examined in laborers, tunnel workers (TW), and operating engineers (OE) in HH and tunnel construction. The principal outcome of interest was airways disease.*

Methods *Subjects were recruited through their unions. Medical and occupational histories and flow-volume loops were obtained. Based on self-report, asthma and chronic bronchitis were categorized as (1) physician-diagnosed or (2) for asthma, undiagnosed likely, and (3) for chronic bronchitis, symptomatic. Trade and time in the union were used as surrogates of exposure. Prevalence of asthma and chronic bronchitis, lung function outcome, and relationships with exposure variables were examined.*

Results *Data were obtained on 389 workers: 186 laborers, 45 TWs, and 158 OEs. Prevalence of asthma was 13 and 11.4% for laborers (including TW) and OEs, respectively, and of symptomatic chronic bronchitis, 6.5 and 1.9%, respectively. Odds ratios (OR) for undiagnosed asthma likely were significantly elevated in TWs compared to OEs, and marginally elevated for chronic bronchitis. Inverse relationships were observed between time in the union, and risk for asthma and chronic bronchitis. Asthma (physician-diagnosed or undiagnosed likely) predicted lower FEV_1. Current cigarette use was associated with chronic bronchitis but not asthma.*

Conclusions *TWs, laborers, and OEs in HH construction are at increased risk for asthma. TWs also appear to be at increased risk for chronic bronchitis. Our data suggest that symptomatic workers are self-selecting out of their trade. Asthma was associated with lower lung function in those affected.* Am. J. Ind. Med. 40:73–86, 2001.

KEY WORDS: heavy and highway construction; tunnel workers; laborers; operating engineers; asthma; healthy worker effect

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INTRODUCTION

Occupational exposures for workers in heavy and highway (HH) construction include dusts, inhalable and respirable, and irritant particulates, vapors, and fumes [Malek, 1998; Weeks, 1998]. Principal among these exposures are diesel exhaust (DE), silica, cement and concrete dust, and welding and asphalt fumes [Greenspan et al., 1995]. The number of workers at risk for these exposures is large and growing. The construction industry employed 4,986,000 workers in the United States in 1994 and close to six million workers in 1998. Of these, approximately 850,000 (14%) are employed in HH construction [Anonymous, 1995a, b, 1999]. Although construction-related injuries are tracked and reported, health hazards associated with work in this industry have not been well characterized. Specifically, respiratory effects of exposure to dusts and irritants have not been described either in terms of symptoms or impact on lung function.

Health effects of exposure to air-borne dusts at work in other industries have been examined. These effects include respiratory symptoms, decrement in lung function, and obstructive lung disease—both acute and chronic. Associations between asthma and exposure to air-borne dusts have been observed in carpenters and in cement workers [Lipscomb and Dement, 1998; Alvear-Galindo et al., 1999]. In a cohort study of lung disease in union carpenters, Lipscomb and Dement [1998] found that airways disease accounted for the majority of lung disease diagnoses. In a nested case-control study of the same cohort, investigators observed significantly increased odds ratios (OR) for asthma for occupational exposures to dusts commonly found on HH construction work sites. Alvear-Galindo et al. [1999] reported significant associations between cement dust exposure and symptoms of bronchitis, wheeze, and acute upper respiratory tract diseases in a population of Portland cement plant workers. Other investigators have reported associations between occupational exposure to cement dust and the occurrence of asthma [DeRaeve et al., 1998]. Becklake [1985, 1989] reviewed published data on relationships between occupational dust exposures and the development of chronic obstructive pulmonary disease (COPD) in workers in dusty occupations. She concluded that occupational exposure to dusts constitutes a risk factor for COPD and that acute airway responses to these exposures likely predicts the development of COPD. Heederik et al. [1994] documented correlations between exposures to inhalable and respirable dusts and respiratory symptoms and reduction in air flow rates and forced vital capacity (FVC) in longshoremen.

In addition to dusts, workers in HH construction are exposed to DE. Diesel emissions contain a particulate component and a vapor phase. Both are irritants and have been associated with adverse respiratory effects in exposed workers, including asthma, decrement in lung function, and acute airway and systemic inflammatory responses in healthy subjects [Ulfvarson et al., 1990; Wade and Newman, 1993; Salvi et al., 1999]. Filtration of DE fumes may result in improvement in exposure-related symptoms and lung function [Ulfvarson et al., 1990, 1991; Rudell et al., 1996, 1999].

The present study examines acute and chronic respiratory effects of workplace exposures in HH and tunnel construction workers. Targeted for study were operating engineers (OE) and laborers (including tunnel workers (TW)) on a large highway and tunnel construction project in the northeastern United States. The purpose of the project was to depress the central artery that runs through a large metropolitan area, linking areas to the north and south. Principal work activities included (1) cut and cover tunnel construction using (a) slurry walls and (b) cast-in-place reinforced and steel composite concrete, (2) excavation and tunneling under an existing railroad station, and (3) rebuilding existing off-ramp and street decking, and new surface roadway exit ramps. The number of construction workers employed on the project increased from 805 in 1992 to a projected 3,929 workers in the Year 2000. OEs and laborers (including TW) constituted the largest number of workers—accounting for 1,231,319 and 1,017,246 person-hours worked between start-up of the project in the fall of 1992 and 1 June 1999, respectively.

Baseline and annual follow-up examinations of workers in targeted trades were carried out to obtain information about respiratory symptoms, work history, and lung function. The principal respiratory outcome of interest and the focus of this report is airways disease. Symptoms of asthma and chronic bronchitis, physician-diagnosed asthma, and lung function are examined and compared within and between trades. Surrogates for exposure are defined and relationships with respiratory outcome evaluated. This report presents results of cross-sectional analysis of baseline data collected through 1 June 1999.

MATERIALS AND METHODS

Study Population

Selection

Laborers, OEs, and TWs were invited to participate in the study. General construction laborers and TWs were members of the Laborers International Union of North America (local union numbers are dummy variables). OEs were members of a large local union of the International Union of Operating Engineers. These trades were selected on the basis of the type of work done in HH and tunnel construction.

Recruitment

Study participants were recruited at local union meetings and OE apprentice training sessions. At these meetings investigators described the goals of the study and the nature of the medical evaluations, emphasizing medical confidentiality. A lottery for a $1,200 travel voucher was offered to participating members of each local union during each year of the study as an incentive to participation. Drawings were held just prior to recruitment for the next survey.

For each local union, two surveys were held each year. Addresses and telephone numbers were obtained from interested members. Questionnaires were mailed out 2 weeks prior to the date of the survey. During the week preceding the survey, telephone calls were made to those who signed up to remind them of the date and time of their examination.

Medical Evaluation

Baseline and annual follow-up examinations were carried out. These included questionnaires, lung function tests, and physical examination.

Questionnaire

Detailed questionnaires obtained information about work history, current and previous health status, tobacco and alcohol use, and stress. Work histories were trade-specific and collected information about current industry and current job, date of initiation into the union, percent of time worked at the trade since initiation, work on the construction site that was the focus of the study, and previous and usual jobs. Questionnaires were self-administered and reviewed by a trained interviewer at the time of the survey.

Smoking and respiratory histories were derived from the Epidemiology Standardization Project questionnaire and from the Venables questionnaire for asthma epidemiology [Ferris, 1978; Venables et al., 1993]. Based on answers to questions about physician-diagnosed asthma and reported symptoms of cough and wheeze, participants were categorized as diagnosed asthma, undiagnosed asthma likely, no asthma, or missing information. Participants who answered ''yes'' to the question ''Have you ever had asthma?'' and ''yes'' to the question ''Was it confirmed by a doctor?'' or reported current use of asthma medication were classified as physician-diagnosed asthma. Undiagnosed asthma likely was determined on the basis of reports of symptoms of cough and wheeze according to the algorithm presented in Figure 1, an algorithm based on the Venables study and previously tested in a community-based health survey designed to estimate asthma prevalence [Venables et al., 1993; Oliver et al., 1998].

Symptomatic chronic bronchitis was determined on the basis self-reported symptoms of cough and phlegm as much as 4–6 times a day for 4 or more days of the week for at least 3 months a year for 2 or more consecutive years [Fletcher et al., 1959]. Participants not meeting these criteria were classified as having no symptomatic chronic bronchitis. Participants who answered ''yes'' to the question ''Have you ever had chronic bronchitis?'' *and* ''yes'' to the question ''Was it confirmed by a doctor?'' were classified as physician-diagnosed chronic bronchitis.

Question design did not allow detailed examination of health care use patterns. However, we were able to examine healthcare utilization in the past year (yes/no).

Pulmonary function tests

Maximal expiratory flow-volume loops were obtained using the Morgan Spiro 232 spirometer (PK Morgan Ltd., Kent, Sussex, UK), with a minimum of three acceptable maneuvers. Tests were performed by experienced pulmonary technicians. Forced expiratory volume in 1 s (FEV_1) and FVC maneuvers were considered repeatable if the two best values for each agreed within 10% of the larger value or 200 ml [Anonymous, 1995a, b]. Maximal values for FEV_1 and FVC were used in data analysis. The ratio of FEV_1/FVC was calculated from these values and used in data analysis. Predicted values were derived from prediction equations of Knudsen et al. [1983]. The observed values for FEV_1 and FVC were expressed as a percentage of the age-, height-, and gender-based predicted values. An obstructive defect was defined as an FEV_1 less than 80% of the predicted value *and* an FEV_1/FVC less than 70%, a restrictive defect, as an FVC less than 80% predicted *and* an FEV_1/FVC of 70% or greater.

Physical Examination

Height was measured in inches without shoes. Weight was a self-reported estimate.

Exposure Characterization

Workplace exposures of interest were dusts and DE. Sources of dust included excavated soil and dust from cement batch plants, concrete mixing and filling, grout work, and demolition of existing highway structures. The principal source of DE was heavy equipment operated by OEs. OEs were subdivided into apprentice OEs (trainees enrolled in a 4-year apprentice program) and journey level OEs (those who had successfully completed their apprenticeship). Job category was also used to characterize exposures for OEs. Using information provided by experienced journey level OEs about the general nature of their work, we collapsed job classifications reported by appren-

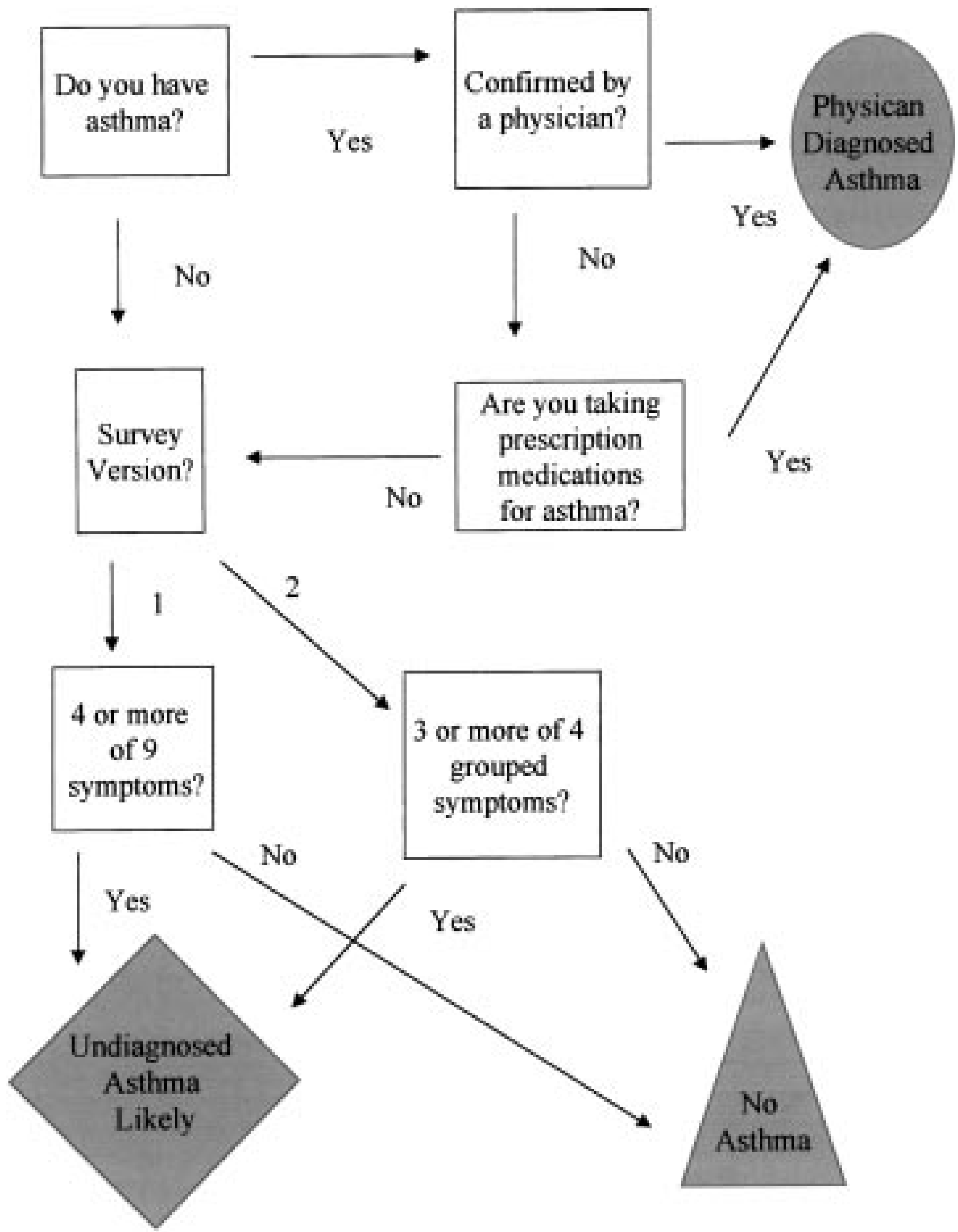

FIGURE 1. Asthma Algorithm.

tice and journey level OEs into fewer categories to allow more meaningful data analysis. Backhoe, bulldozer, front end loader, combination hoe and bobcat operators, and excavator were collapsed into ‘‘excavator’’; swing crane and tower crane, into ‘‘swing crane’’; and oiler and mechanic, into ‘‘mechanic’’. Those OEs who reported as their current work jobs falling into more than one of the three job categories above, those reporting cement or asphalt work, or those reporting ‘‘other’’ work were grouped into ‘‘other’’. For general construction laborers, the use of job category to define exposure was not possible because of the varied nature of their work. Duration of work at the trade was used for all workers as a surrogate for length of exposure in data analysis.

Data Analysis

Analysis of variance was used to assess the relationship between lung function outcomes expressed as continuous variables (FEV_1, FVC, FEV_1/FVC, and percent predicted for FEV_1 and FVC) and labor group (as defined by trade and local union) and OE job category [Johnson and Wichern, 1992]. To control for the possible confounding effects of other covariates, analysis of covariance was used. If the overall *P*-value from the adjusted model for labor groups was significant ($P < 0.05$), pair-wise comparisons between labor groups were performed. Linear regression was used to model the relationship between continuous lung function outcomes and duration in the union [Johnson and Wichern, 1992].

Relationships between lung function and respiratory symptoms were also examined. In published studies of associations between occupational exposures and obstructive pulmonary diseases, both FEV_1 and FEV_1/FVC have been used to define outcome [Annesi and Kauffman, 1986; Becklake, 1989]. In this study, FEV_1 was chosen as the outcome of interest for asthma because asthma characteristically affects lung function acutely and is not likely to be associated with chronic and irreversible obstruction in active construction workers. For chronic bronchitis, FEV_1/FVC was chosen as the relevant lung function outcome because chronic bronchitis is more likely to be associated with COPD, even among active workers.

Logistic regression was used to model the relationship between dichotomous outcomes (restriction, obstruction, asthma, and symptomatic chronic bronchitis) and labor union groups [Hosmer and Lemeshow, 1989]. Models were estimated treating labor/trade group in two ways for these dichotomous outcomes: (1) with OEs as the referent group including an indicator variable for laborers (including TWs) and (2) with journey level OEs as the referent group including separate indicators for Locals 1, 2, and 3 and apprentice OEs. Asthma was analyzed in two ways, first as asthma (physician-diagnosed or undiagnosed likely) vs. no asthma and second as undiagnosed asthma likely vs. no asthma. Unadjusted ORs and 95% confidence intervals (CI) were calculated for each of the exposure variables (labor group, duration in the union, and job category for OEs) and for these additional covariates: age, gender, race, healthcare usage, smoking status, and weight to height ratio. To assess the relationships of outcome to exposure variables while controlling for possible confounding effects of the covariates, adjusted ORs were calculated from models that included both exposure variables and the other covariates.

Self-reported symptoms of chronic bronchitis did not correlate well with self-reported physician-diagnosed chronic bronchitis. Of those with symptoms of chronic bronchitis, only 22% reported a physician diagnosis of chronic bronchitis. Of those with physician-diagnosed chronic bronchitis, only 29% also had symptomatic chronic bronchitis. Because "chronic bronchitis" may be diagnosed by physicians in individuals who fail to meet the standardized definition of chronic bronchitis used epidemiologically, symptomatic chronic bronchitis was considered a more reliable classification and was used in data analysis.

Covariates with missing data included race, smoking status, weight to height ratio, and duration in the union. Approximately 30% of the 389 participants were missing information for at least one of these covariates, and for most the missing data was duration in the union or weight to height ratio. Duration was missing in 74 cases because participants did not report their date of initiation into the union. Because only 358 of the 389 participants had physical measurements taken, there were several with missing data on weight and height. Because of the large number of participants with missing information and the small number of outcomes of interest, those participants with missing information on a covariate were not excluded from multivariate models. Instead, an indicator variable for the missing category was included (results not shown) [Kelsey et al., 1986]. Continuous variables with missing data were first categorized and an indicator for missing information was included along with the category indicators. It was not possible in some models to adjust the relationships for all of the covariates. For example, all reports of chronic bronchitis were among white/non-Hispanic participants. Therefore, it was not possible to adjust for race when analyzing chronic bronchitis.

RESULTS

A total of 359 workers were examined, and questionnaire data were obtained for these workers and from an additional 30. Of these, 231 (59.4%) were laborers and 158 (40.6%), OEs. Among laborers, 104, 82, and 45 were members of Locals 1, 2, and 3, respectively. The number of journey level OEs was 99 and apprentices 59. Slightly more than half of the participants had ever worked on the HH construction project of interest (53.0%), with the highest proportion from Local 2 (69.5%) and lowest from Local 1 (41.4%).

Demographic and Exposure Characteristics

Demographic data, smoking histories, and information about use of the healthcare system for the total group and by trade are shown in Table I. Age varied across labor groups, with OE journeymen being the oldest on average (46.7 years) and OE apprentices being the youngest (30.6 years). Participants were predominantly male (91.5%), with Local 2 having the lowest proportion of female workers (0.0%) and OE apprentices having the highest (16.2%). Weight to height ratio (kg/cm) was higher in OEs than in laborers ($P = 0.0312$). Overall, 28.8% of workers were current smokers, 32.4% former smokers, and 38.3% never smokers. The highest proportion of current smokers was among TWs (40.4%) and the lowest, among OE journeymen (17.2%). Although fewer OEs were current cigarette smokers, those

TABLE I. Descriptive Characteristics of Highway and Tunnel Construction Workers by Trade Group

	Laborers		Operating engineers		Total	
	N	% or mean (SD)	N	% or mean (SD)	N	% or mean (SD)
Total	231	59.4%	158	40.6%	389	100.0%
Age (yrs)	231	41.4 (10.5)	158	41.4 (12.0)	389	41.4 (11.1)
Race/ethnicity						
White/non-Hispanic	203	87.9%	139	88.0%	342	87.9%
Black/non-Hispanic	13	5.6%	8	5.1%	21	5.4%
Other	14	6.1%	9	5.7%	23	5.9%
Missing	1	0.4%	2	1.3%	3	0.8%
Gender						
Male	214	92.6%	142	89.9%	356	91.5%
Female	17	7.4%	16	10.1%	33	8.5%
Weight/height ratio (kg/cm)						
With data	215	0.49 (0.08)	123	0.52 (0.08)	338	0.50 (0.08)
Missing data	16		35		51	
Smoking status						
Never	78	33.8%	71	44.9%	149	38.3%
Former	77	33.3%	49	31.0%	126	32.4%
Current	76	32.9%	36	22.8%	112	28.8%
Missing	0	0.0%	2	1.3%	2	0.5%
Number of packs per day (among current smokers)						
$<\frac{1}{2}$ pk/day	9	11.8%	6	16.7%	15	13.4%
$\frac{1}{2}$ pk/day– $<$ 1 pk/day	28	36.8%	7	19.4%	35	31.3%
1 pk/day– $<$ 2pks/day	34	44.7%	18	50.0%	52	46.4%
$\geq$ 2pks/day	5	6.6%	3	8.3%	8	7.1%
Missing	0	0.0%	2	5.6%	2	1.8%
Total pack-years of smoking (among ever smokers)						
With data	144	20.82 (18.18)	78	22.34 (23.48)	222	21.35 (20.16)
Missing data	9		7		16	
Sought health care in the last year?						
Yes	180	77.9%	130	82.3%	310	79.7%
No	51	22.1%	28	17.7%	79	20.3%

that smoked tended to smoke more cigarettes per day than laborers.

Exposure characteristics for the study population according to trade are presented in Table II. Average duration of time in the union for the group as a whole was 11.3 years (SD = 11.3), with journey level OEs having the highest mean duration (18.0 years) and OE apprentices, the lowest (2.0 years). Breakdown of job category by level of training for OEs showed considerable variability, with the majority of journey level OEs classified as excavators (34% compared to 3% for apprentices) and the majority of apprentices classified as mechanics (42% compared to 13% for journey level OEs).

Lung Function

Specific results of lung function tests are shown by trade in Table III. Mean test results were within the normal range overall, by trade, and within each trade (results not shown). Prevalence of observed respiratory defects by trade is shown in Table IV. Restriction occurred more commonly in OEs than laborers (3.8% vs. 1.7%), with the difference being accounted for by journey level OEs. There was a notable difference in occurrence of restriction between the two general laborers' local unions. Among OEs 6.1% of journey level participants had obstruction compared to none of the apprentices.

TABLE II. Exposure Characteristics of Highway and Tunnel Construction Workers by Trade Group

	Laborers		Operating engineer		Total	
	N	% or mean (SD)	N	% or mean (SD)	N	% or mean (SD)
Laborers union						
Local 1	104	26.7%			104	26.7%
Local 2	82	21.2%			82	21.2%
Local 3	45	11.6%			45	11.6%
Operating engineers						
Status						
Journey			99	62.7%	99	62.7%
Apprentice			59	37.3%	59	37.3%
Current job category						
Excavator			36	22.8%	36	22.8%
Mechanic			38	24.1%	38	24.1%
Swing crane			14	8.8%	14	8.8%
Other			26	16.5%	26	16.5%
Missing			44	27.9%	44	27.9%
Duration in the union (years)	183	11.0 (10.1)	132	11.7 (12.9)	315	11.3 (11.3)
Missing	48		26		74	
Ever on the CAT?						
Yes	128	55.4%	78	49.4%	206	53.0%
No	103	44.6%	80	50.6%	183	47.0%

When relationships between lung function and respiratory symptoms were examined, asthma (either physician-diagnosed or undiagnosed likely) predicted lower FEV_1, and $FEV_1\%$ predicted in the adjusted model: mean FEV_1 (L) was 3.49 (standard error (SE) = 0.04) for asthma vs. 3.86 (SE = 0.09) for no asthma ($P = 0.0002$); mean $FEV_1\%$ predicted was 92.7 (SE = 2.48) for those with asthma vs. 99.9 (SE = 0.97) for those with no asthma ($P = 0.0070$). FEV_1/FVC was not significantly different in those with symptomatic chronic bronchitis compared to those without: mean FEV_1/FVC was 77.0% (SE = 1.75) for those with symptomatic chronic bronchitis and 79.8% (SE = 0.38) for those without chronic bronchitis ($P = 0.1199$).

Respiratory Symptoms

The prevalence of asthma and chronic bronchitis is shown by trade in Table IV. For study participants as a group, overall prevalence of asthma was 12.4%: 9.3% for physician-diagnosed asthma and 3.1% for undiagnosed likely. Asthma, either diagnosed or undiagnosed likely, was only slightly more common among laborers (13.0%) than

TABLE III. Lung Function Outcomes of Highway and Tunnel Construction Workers by Trade Group

	Laborers		Operating engineer		Total	
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
FEV1	213	3.8 (0.76)	123	3.8 (0.72)	336	3.8 (0.74)
FVC	213	4.8 (0.84)	123	4.7 (0.81)	336	4.8 (0.83)
FEV1/FVC %	213	79.5 (7.07)	123	80.0 (6.83)	336	79.7 (6.98)
% predicted FEV_1	211	99.6 (16.49)	123	97.9 (15.44)	334	99.0 (16.11)
% predicted FVC	211	103.2 (14.40)	123	100.6 (13.65)	334	102.2 (14.16)

TABLE IV. Respiratory Outcomes of Highway and Tunnel Construction Workers by Trade Group

	Laborers		Operating engineers		Total	
	N	%	N	%	N	%
Asthma						
Physician diagnosed	19	8.2	17	10.8	36	9.3
Undiagnosed likely	11	4.8	1	0.6	12	3.1
None	199	86.2	138	87.3	337	86.6
Missing	2	0.9	2	1.3	4	1.0
Chronic Bronchitis						
Symptomatic						
Yes	15	6.5	3	1.9	18	4.6
No	212	91.8	152	96.2	364	93.6
Missing	4	1.7	3	1.9	7	1.8
Self-reported physician diagnosed						
Yes	7	3.0	7	4.4	14	3.6
No	216	93.5	144	91.1	360	92.5
Missing	8	3.5	7	4.4	15	3.9
Restriction						
Yes	4	1.7	6	3.8	10	2.8
No	206	89.2	114	72.2	320	82.3
Missing	21	9.1	38	24.1	59	15.2
Obstruction						
Yes	10	4.3	6	3.8	16	4.1
No	200	86.6	114	72.2	314	80.7
Missing	21	9.1	38	24.1	59	15.2

OEs (11.4%). However, laborers were more likely to have undiagnosed asthma. TWs had the highest prevalence of asthma (20.0%), as well as the highest prevalence of undiagnosed asthma likely (11.0%). More laborers than OEs reported symptoms of chronic bronchitis; prevalence was highest among TWs (13.3%). Journey level and apprentice OEs were similar with regard to both asthma and symptoms of chronic bronchitis. (Results for subgroups within trade are not shown.)

We investigated the statistical significance of the relationship between asthma outcome and possibly relevant covariates (Table V). Gender was a significant predictor of asthma outcome, with females being at increased risk compared to males (OR = 3.43, 95% CI = 1.23, 9.60, adjusted). Being of race other than Caucasian significantly protected against asthma (OR = 0.11, 95% CI = 0.01, 0.95, adjusted). Relationships between asthma and tobacco use defined by smoking status, current cigarettes smoked per day, and pack-years of smoking were not significant (results not shown for number of cigarettes or pack-years). Compared to journey level and apprentice OEs combined, TWs had the highest risk of asthma (OR = 2.67, 95% CI = 1.02, 6.96, adjusted).

The occurrence of undiagnosed asthma likely (vs. no asthma) was higher in laborers compared to journey level OEs, but the difference was only marginally significant (OR = 6.84, 95% CI = 0.86, 54.24, adjusted) (Table VI). However, for TWs the increase in risk for undiagnosed asthma likely was strikingly significant compared to journey level OEs (OR = 20.28, 95% CI = 2.22, 185.12, adjusted).

Although the risk for symptomatic chronic bronchitis was significantly increased in laborers compared to OEs in the unadjusted model (OR = 3.59, 95% CI = 1.02, 12.60), the relationship was no longer significant after adjusting for other covariates (OR = 3.07, 95% CI = 0.75, 12.58) (results not shown). The risk for symptomatic chronic bronchitis in TWs compared to journey level OEs was only marginally elevated (OR = 6.49, 95% CI = 0.97, 43.33, $P = 0.0534$, adjusted) (Table VII). However, when TWs were compared to journey level and apprentice OEs combined, their increase in risk was statistically significant (OR = 7.50, 95% CI = 1.49, 37.73, adjusted). Increasing age was

TABLE V. Logistic Regression Results for Asthma (Physician Diagnosed Likely or Undiagnosed Likely) Versus no Asthma in Highway and Tunnel Construction Workers

	Unadjusted		Adjusted	
	Odds ratio	95% CI	Odds ratio	95% CI
Labor group				
Journey OE	1.00	—	1.00	—
Apprentice OE	1.05	0.38,2.89	0.67	0.19,2.37
Local 1	0.74	0.29,1.87	0.72	0.26,1.93
Local 2	1.38	0.57,3.32	1.72	0.65,4.54
Local 3 (TW)	1.95	0.75,5.12	2.27	0.78,6.66
Duration in union				
< 2 years	1.00	—	1.00	—
>= 2, < 8 years	0.79	0.33,1.92	0.73	0.27,1.96
>= 8, < 17 years	0.55	0.21,1.45	0.59	0.20,1.77
>= 17 years	0.57	0.22,1.52	0.51	0.14,1.87
Age (continuous, yrs)	0.986	0.959,1.014	0.999	0.956,1.043
Gender				
Male	1.00	—	1.00	—
Female	3.01	1.31,6.94	3.43	1.23,9.60
Race				
White/Non-Hispanic	1.00	—	1.00	—
Other	0.15	0.02,1.13	0.11	0.01,0.95
Health care usage in the last year?				
Yes	1.14	0.53,2.46	0.99	0.43,2.28
No	1.00	—	1.00	—
Weight/height (kg/cm)				
< 0.45	1.00	—	1.00	—
>= 0.45, < 0.55	1.01	0.45,2.28	1.22	0.50,2.95
>= 0.55, < 0.65	1.66	0.69,4.00	2.72	0.99,7.49
>= 0.65	0.38	0.05,3.12	0.40	0.05,3.53
Smoking status				
Never	1.00	—	1.00	—
Former	0.91	0.43,1.92	1.08	0.47,2.51
Current	1.14	0.55,2.38	0.99	0.44,2.23

significantly associated with increasing risk for symptomatic chronic bronchitis (OR = 1.078, 95% CI = 1.003, 1.159 (for each year of age)). Unlike asthma, current cigarette use (compared to never smoking) was a risk factor for chronic bronchitis. There was a marginally significant increase in risk for chronic bronchitis with increasing number of pack-years of cigarettes among ever smokers and a significant increase in risk with increasing current packs per day for current smokers (Test for trend, $P = 0.0772$ and 0.0040, respectively). Smokers currently smoking more than two packs per day were 60 times more likely to experience symptomatic chronic bronchitis (OR = 61.06, 95% CI = 9.95, 374.55, adjusted).

Exposure–Response Relationships

Length of time in the union was used as a surrogate for duration of work at the trade. Health outcomes were examined by trade, by duration in the union and, for OEs, by job category. When adjusted means for measured lung function outcomes were analyzed by labor group, duration in the union, and job category (for OEs), the only significant relationship was between FVC% predicted and labor group ($P = 0.0119$), with participants from Local 1 having significantly higher FVC% predicted (adjusted mean (SE) 105.8 (1.4) than participants from Local 2 (99.0 (1.6)), OE apprentices (99.6 (3.9)), and OE journey level (101.3 (1.6)). Mean FVC% predicted for participants from Local 3 was similar to Local 1 (104.0 (2.1)). Occurrence of restriction or obstruction was not significantly different in laborers compared to OEs in either the adjusted or the unadjusted model.

For the study group as a whole, risk for asthma decreased with increasing time in the union, but a test for trend was not significant ($P = 0.6144$). Using excavators as the referent group, the risk for asthma was increased in all other job categories of OEs but the differences were not significant. There was a significant decrease in risk for chronic bronchitis with increasing time in the union for both trades combined ($P = 0.0461$, adjusted model). Because of small numbers in each job category, we were unable to statistically analyze prevalence of chronic bronchitis by OE job category.

DISCUSSION

The present study examines respiratory health effects of work in HH construction for general laborers, tunnel workers, and OEs. Our findings reveal a higher prevalence of respiratory symptoms among laborers compared to OEs. Overall prevalence of asthma (physician-diagnosed and undiagnosed likely) was similar among general construction laborers and OEs, and significantly higher among TWs. Undiagnosed asthma likely was more common among laborers than OEs, although the difference was significant only for TWs. ORs for symptomatic chronic bronchitis were highest for TWs and lowest for OE apprentices. Lung function was normal for both trades and no significant differences were observed between trades. However, among labor groups (after adjustment for covariates) significant differences were observed in FVC% predicted. Restriction was more common among OEs and Local 2 participants. Obstruction was more common among journey level OEs compared to apprentices.

Factors responsible for the observed differences in respiratory outcome are not clear. Demographic variables were

TABLE VI. Logistic Regression Results for Undiagnosed Asthma Likely Versus no Asthma by Trade in Highway and Tunnel Construction Workers

	Unadjusted		Adjusted[a]	
	Odds ratio	95% CI	Odds ratio	95% CI
Operating engineers	1.00	—	1.00	—
Laborers	7.63	0.97,59.77	6.84	0.86,54.24
Operating engineers	1.00	—	1.00	—
Local 1	4.36	0.45,42.53	3.53	0.35,35.30
Local 2	6.09	0.62,59.63	5.03	0.50,50.27
Local 3 (TW)	19.17	2.17,169.24	20.28	2.22,185.12

[a]Adjusted for age, duration in union, health care usage in the last year and smoking status.

TABLE VII. Logistic Regression Results for Symptomatic Chronic Bronchitis in Highway and Tunnel Construction Workers

	Unadjusted		Adjusted	
	Odds ratio	95% CI	Odds ratio	95% CI
Labor group				
Journey OE	1.00	—	1.00	—
Apprentice OE	0.83	0.07,9.40	0.73	0.05,10.87
Local 1	1.44	0.24,8.81	0.97	0.14,6.92
Local 2	3.75	0.74,19.11	3.23	0.51,20.58
Local 3 (TW)	7.70	1.49,39.90	6.49	0.97,43.33
Duration in union				
< 2 years	1.00	—	1.00	—
>= 2, < 8 years	0.71	0.20,2.56	0.70	0.16,3.14
>= 8, < 17 years	0.29	0.06,1.57	0.28	0.04,1.75
>= 17 years	0.30	0.06,1.61	0.21	0.03,1.82
Age (continuous, yrs)	0.998	0.956,1.042	1.078	1.003,1.159
Gender				
Male	1.00	—	1.00	—
Female	0.61	0.08,4.74	0.69	0.07,7.22
Health care usage in the last year?				
Yes	0.45	0.16,1.25	0.50	0.61,1.63
No	1.00	—	1.00	—
Weight/height (kg/cm)				
< 0.45	1.00	—	1.00	—
>= 0.45, < 0.55	0.98	0.30,3.16	1.02	0.26,3.94
>= 0.55, < 0.65	0.86	0.20,3.70	1.28	0.23,7.25
>= 0.65	0.94	0.10,8.49	0.60	0.04,9.15
Smoking status				
Never	1.00	—	1.00	—
Former	0.29	0.03,2.63	0.20	0.02,2.08
Current	4.98	1.58,19.73	6.37	1.79,22.71

similar between trades. Observed differences in weight to height ratio although statistically significant were slight and not likely to affect either respiratory symptoms or lung function. More laborers than OEs were current or former smokers, but the differences were small. And while cigarette use was associated with chronic bronchitis, it was not associated with asthma in multivariate analysis. No significant differences in healthcare utilization (yes/no) were observed, but this does not rule out differences in patterns of utilization that may explain the observed difference in prevalence of undiagnosed asthma. Under-reporting of physician-diagnosed asthma by laborers may also be a factor. In their study of HMO members, Milton et al. [1998] found that 43% of new-onset and 9% of reactivated (diagnosed) asthma cases failed to report physician-diagnosed asthma when completing a standardized questionnaire.

Differences in workplace exposures may explain observed differences in prevalence of respiratory symptoms. For example, TWs are more likely to work in enclosed or partially enclosed spaces compared to OEs and general construction laborers, and thus experience higher level exposures to air-borne toxins. Qualitatively, potentially toxic workplace exposures for all participants are similar and include irritants in DE and in cement-containing dusts. Both particulate and vapor-phase components of DE contain irritants that appear to have additive effects on the respiratory tract [Amdur and Underhill, 1968; Costa and Amdur, 1996].

DE and cement dusts have been associated with airways hyper-reactivity and asthma. The development of new-onset asthma was reported in three railroad workers exposed to relatively high levels of DE [Wade and Newman, 1993]. In a study of healthy volunteers exposed during light exercise to air, particulate-filtered DE, and nonfiltered DE from an idling lorry, Rudell et al. [1996] observed significant increases in airway resistance in those exposed to DE. Filtration of particulates had no effect on lung function despite a 46% reduction in particle numbers. Results of a later study indicated that filtration of particulates alone may not be enough to significantly reduce adverse health effects of DE because of irritants in the vapor phase [Rudell et al., 1999].

Salvi et al. [1999] reported airway inflammation associated with exposure to unfiltered DE in a study of healthy human subjects. Increases in neutrophils, B-lymphocytes, histamine, and fibronectin were found in airway lavage; and bronchial biopsies showed increases in neutrophils, mast cells, and other markers of inflammation. Ventilatory test results before and after each exposure were unchanged, a finding that lead the authors to conclude that standard lung function tests are an insensitive measure of airway response.

Exposure to cement-containing dusts may also put workers at risk for airways disease. Mechanisms may include not only irritation and inflammation but also an immunologically mediated response to Cr^{VI} in cement [DeRaeve et al., 1998]. In a cross-sectional study of workers in a Portland cement plant, bronchitis, wheeze, acute upper respiratory tract disease, and "occupational respiratory disease" were significantly associated with level of exposure to cement dust [Alvear-Galindo et al., 1999]. ORs (adjusted) for certain dusts were significantly elevated among cases of asthma compared to controls in a study of respiratory disease in union carpenters. These dusts included cement, lime, and mixed dust from sweeping/demolition [Lipscomb and Dement, 1998].

Chronic bronchitis and COPD have also been associated with occupational exposure to dusts [Becklake, 1985, 1989]. In her published review, Becklake [1985] summarized cross-sectional study results that showed increased prevalence of bronchitis and decreased air flow rates in dust-exposed compared to nonexposed workers in the mining industry. Longitudinal studies of workers in various dusty occupations, including one study of construction workers in France, showed greater decline in ventilatory function over time in dust-exposed workers, providing evidence of a causal association between COPD and occupational exposure to dust [Becklake, 1989]. In multivariate analysis controlling for age and smoking, Heederik et al. [1994] found significant relationships between shortness of breath and current, and cumulative dust exposures in exposed stevedores compared to their nonexposed counterparts. Symptoms of cough and sputum were also more common. FEV_1 and FVC were significantly and inversely associated with current and cumulative dust exposures, although not with total years in a dusty job. In their study of union carpenters using workers' compensation and health insurance claims data, Lipscomb and Dement [1998] found that bronchitis accounted for 54.9% of lung diagnoses by ICD-9 code, chronic bronchitis for 5.5%, and chronic obstructive airway (NOC) for 9.7%. Rates of chronic bronchitis and COPD increased with increasing age, consistent with our own findings regarding chronic bronchitis.

Both asthma and chronic mucus hyper-secretion have been associated with increased morbidity and loss of lung function in studies of workers and the general population [Vestbo et al., 1996; Lange et al., 1998; Annesi and Kauffmann, 1986; Liss et al., 1999]. In the present study, either physician-diagnosed asthma or likely undiagnosed asthma predicted lower FEV_1 and increasing age was associated with increasing risk for chronic bronchitis. In members of the general population who identified themselves as having asthma, Lange et al. [1998] found significant decline in FEV_1 over time, greater in smokers than in nonsmokers. In a study by Vestbo et al. [1996], chronic mucus hyper-secretion was associated with significant decline in FEV_1 and an increase in risk for hospitalization for COPD after adjusting for FEV_1. Asthma diagnosis and chronic mucus hyper-secretion have been associated with increased mortality in working populations [Liss et al., 1999; Annesi and Kauffman, 1986].

Although statistically significant for chronic bronchitis only, our results showed decreasing prevalence of disease with increasing years in the trade both for asthma and for chronic bronchitis, a finding consistent with self-selection out of the trade because of symptoms of acute and chronic airways disease—the so-called "healthy worker" effect. Similar results were observed for asthma by Lipscomb and Dement [1998] in their study of union carpenters, by Alvear-Galindo et al. [1999] in their study of Portland cement plant workers, and by Petsonk et al. [1995] in their study of underground coal miners. For asthma defined on the basis of symptoms in carpenters, ORs were lower for one or more years in the union compared to less than 1 year. Probability of respiratory disease among Portland cement plant workers decreased as age and levels of exposure increased. In underground coal miners, prevalence of positive airway response to methacholine decreased as time worked at the face of the mine increased.

Our female study participants were at increased risk for asthma compared to males. This finding is consistent with observations by Lipscomb and Dement [1998] that female carpenters were more likely than their male counterparts to report symptoms of asthma. In the present study, all cases of asthma among females were physician-diagnosed compared to 69.2% of cases among males, suggesting that health care use patterns may partially explain findings. Interestingly, Lipscomb and Dement [1998] observed that increases in ORs for irritant dusts were significant when asthma case was defined on the basis of respiratory symptoms, but not when case was defined on the basis of three digit ICD-9 code from either workers' compensation or health insurance claims data.

Potential Weaknesses

Potential weaknesses of the present study are (1) the voluntary nature of participation and low participation rates, creating the possibility of selection bias, (2) the lack of specific air-borne exposure monitoring, (3) the lack of an unexposed comparison group, and (4) small numbers of observed outcomes resulting in a lack of power to detect statistically significant relationships. To address the issue of possible selection bias, we examined the extent to which participants were likely to be representative of all union members with regard to age and duration of work at the trade. Mean age and time in the union for members as a whole were calculated as of 31 December 1996—the period for which complete data were available for laborers.

For OEs, the number of union members for whom data were available was 2,399 (6.6%) and for laborers—1,477 for Local 1 (7.0%), 848 for Local 2 (9.7%), and 494 for Local 3 (9.1%). Mean age for the study group as a whole was 41.4 years (ranging from 20.4 to 70.5 years). For OE journey level study participants, mean age and years worked at the trade were similar to those for all union members (standard deviation in parentheses): for age (yrs), 47.1 (10.7) vs. 44.2 (11.6), respectively; for time in the union (yrs), 18.0 (13.1) vs. 17.7 (12.4). With the exception of Local 2 for whom participants had worked fewer years in the trade, results among participating laborers were similar to all union members: Local 1—age (yrs) 42.4 (11.1) vs. 41.3 (12.0), time in the union (yrs) 12.0 (10.6) vs. 12.0 (10.3); Local 2—age (yrs) 41.2 (9.9) vs. 40.9 (10.7), time in the union (yrs) 10.5 (9.4) vs.13.1 (9.3); Local 3—age (yrs) 39.5 (10.0) vs. 38.5 (9.7), time in the union (yrs) 9.4 (10.0) vs. 9.4 (7.6). As expected, participating OE apprentices were younger than other participants with less time in the union: 31.8 (6.7) years and 2.0 (1.3) years, respectively. These similarities in age and length of time in the union for study participants compared to all union members and the fact that the pool from which study participants were drawn consisted of active construction workers make it unlikely that there were significant differences in basic health status between the two groups. Information on smoking status among nonparticipants was not available, but there is no reason to believe *a priori* that nonparticipating fellow union members of similar age and time in the trade would have smoking habits significantly different from their participating counterparts.

With regard to the lack of specific exposure monitoring, it is generally the case that accurate assessment of air-borne exposures for workers in HH construction is difficult because of the constantly changing nature of the work environment. Not only does the physical site itself change as the project progresses, but the tasks performed by the workers, and the materials and equipment used change. In one published study, a task-based approach was used to evaluate exposures to dust, silica, and asphalt fume for laborers and OEs working on a highway interchange construction project in the northeastern United States [Greenspan et al., 1995]. Personal samples for total and respirable dust and silica were collected during autumn months. Tasks examined included excavation, pipe laying, and grinding and laying asphalt. Although total and respirable dust concentrations were below the permissible exposure limits established by the Occupational Safety and Health Administration, silica constituted 32% (0.17 mg/m^3) and 26% (0.12 mg/m^3) of two of three respirable dust samples collected. The low dust levels were attributed to effective use of water and to the fact that samples were not collected during the (reportedly) hot dry summer months.

Surrogates of exposure were used in the present study. These were duration of work at the trade as estimated by time in the union, differentiation of general construction laborers from TWs, and job category for OEs. TWs as a group are more likely to work in confined spaces, and TWs had higher prevalence of both asthma and chronic bronchitis compared to other participants. For the group as a whole, decreasing prevalence of asthma and chronic bronchitis with increasing duration of work at the trade suggests exposure-related health effects that drive workers from the trade. Thus, these surrogates proved useful in examining exposure–response relationships in a broad sense, but the absence of quantitative and better qualitative exposure data precludes identification of specific cause(s) of observed respiratory health outcome.

A nonexposed referent group was not available for comparison. National Health Interview Survey (NHIS) data were used for external comparisons of prevalence for asthma and chronic bronchitis [US DHHS, 1995]. The NHIS is a telephone interview survey of civilian households in the United States designed to provide estimates of age-specific prevalence of certain acute and chronic medical conditions. Data collected in 1994 provided the following estimates for cases of asthma and chronic bronchitis per 1,000 persons ages 18–44 and 45–64: asthma—51.7 and 50.8, respectively; chronic bronchitis—46.7 and 63.9, respectively. Additional external comparison data were Centers for Disease Control and Prevention (CDC) estimates of 1998 asthma prevalence rates based on 1995 NHIS asthma prevalence data for the four US census regions [Anonymous, 1998]. For the northeastern US, overall asthma prevalence was estimated at 6.7% and for Massachusetts, at 6.5%.

Because definition of a ''case'' in the NHIS was based on a positive response to the question ''Have you had'' asthma or chronic bronchitis, the most appropriate comparison data from our study were determined to be physician-diagnosed asthma and chronic bronchitis, despite our more rigorous definitions of diagnosed asthma and chronic bronchitis. Compared to both 1994 NHIS and more recent CDC data, prevalence of asthma among study participants was elevated for all groups except for laborers Local 1, (5.8%); Local 2, 11.0%; Local 3, 8.9%; journey level OEs, 10.1%; and OE apprentices, 11.9%. Prevalence of physician-diagnosed chronic bronchitis was similar to or slightly lower than estimated NHIS 1994 prevalence rates for the general population ages 18–44: Local 1, 1.9%; Local 2, 3.7%; Local 3, 4.4%; journey level OEs, 4.0%; and OE apprentices, 5.1%.

Because OE apprentices had the shortest length of time in the trade, they might be expected to have the lowest prevalence of adverse respiratory outcomes. This was true for more long-term effects such as restriction and obstruction, but not for more acute respiratory symptoms. None of the apprentices had an obstructive defect on lung function testing and 1.7% had a restrictive defect. Prevalence of asthma and symptomatic chronic bronchitis was similar in apprentices and journey level OEs, and lower compared to laborers: for asthma, 11.9, 11.1, and 13%, respectively; for chronic bronchitis, 1.7, 2.0, and 6.5%, respectively.

Despite small numbers of observed airways disease outcomes among the 389 workers, our data are unique with respect to the large number of HH construction workers recruited for examination of respiratory problems. We may have had insufficient power to detect some differences that would have been significant with a larger data set; but even with small numbers we observed significant differences in the occurrence of asthma and chronic bronchitis among trade/labor groups.

CONCLUSIONS

Based on our findings we conclude that OEs and laborers in HH construction are at increased risk for asthma, and that TWs are at increased risk for chronic bronchitis. As a result, these workers are at increased risk for related morbidity and mortality compared to the general population. Our data further suggest that symptomatic workers are leaving the trade. Standard lung function tests may be an insensitive measure of airway response to workplace irritants and nonirritant dusts.

We believe that improved medical surveillance of workers in HH construction for airways disease is needed. Steps must be taken to intervene to prevent excess morbidity and mortality among affected workers. These steps should include early medical diagnosis and treatment, reduction in workplace exposures to dust and DE, and education of workers with regard to smoking cessation and signs, symptoms, and management of respiratory disease.

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